Flight Systems and Technologies for Impact Detection and Location

In Space Inspection Workshop 2014

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Overview

- Background
- Manned Spaceflight – NASA applications
  - Wing Leading Edge Impact Detection System
  - Distributed Impact Detection System
- Unmanned Spaceflight – Military applications
  - Hit Grids
  - Wireless Hit Grids
- Other Applications
  - Lightning strike detection & location
  - Next Generation Spacecraft HVI detection & location

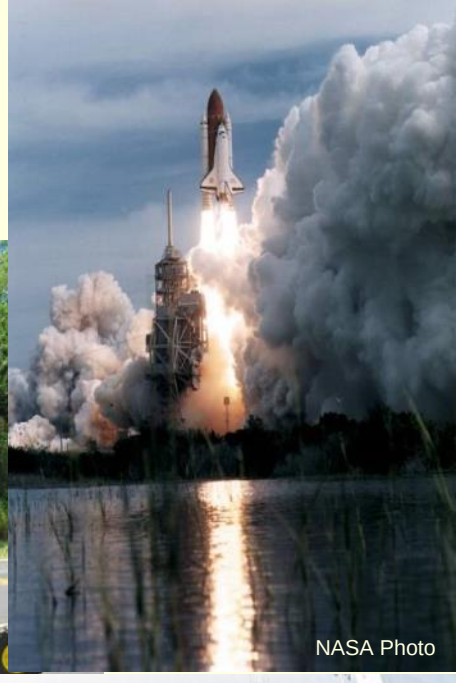
Invocon, Inc.

- Founded in 1985
- Located in Conroe, Texas
- Veteran-owned Small Business
- Employs Electrical Engineers, Technicians, Computer Science and Administrative personnel

Invocon's core activities revolve around *research and development* of *precision instrumentation* and *communication solutions* for *demanding applications* in *extreme environments*.

Applications

- Application Areas:
  - Aircraft / Spacecraft Test and Eval.
  - Mechanical Condition-Based Maint.
  - Missile-Defense
  - Civil Structural Monitoring
- Invocon Flight Systems:
  - Structural Analysis ISS
  - 40+ Shuttle flights, including 17 unique systems
  - 5 systems aboard the ISS
  - 20+ Flights – Instrumentation on Navy/MDA Target Missiles



Rationale for Event-Triggered Inspection

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- Inspections can be too costly or even impossible
- Challenges based on:
  - Vehicle configuration – can't get there to inspect it
  - Vehicle environment – unsafe to inspect
  - Mission objectives – will interfere with mission
  - Mission timeline – don't have time
  - Mission Cost – fuel, personnel, volume, mass, $$
- Considerations:
  - Must minimize triggering instrumentation or risk mission objectives – SWaP-C
  - Triggered events may require re-evaluation of mission
- However: If it isn't broken, don't meddle with it!

Wing Leading Edge Impact Detection System

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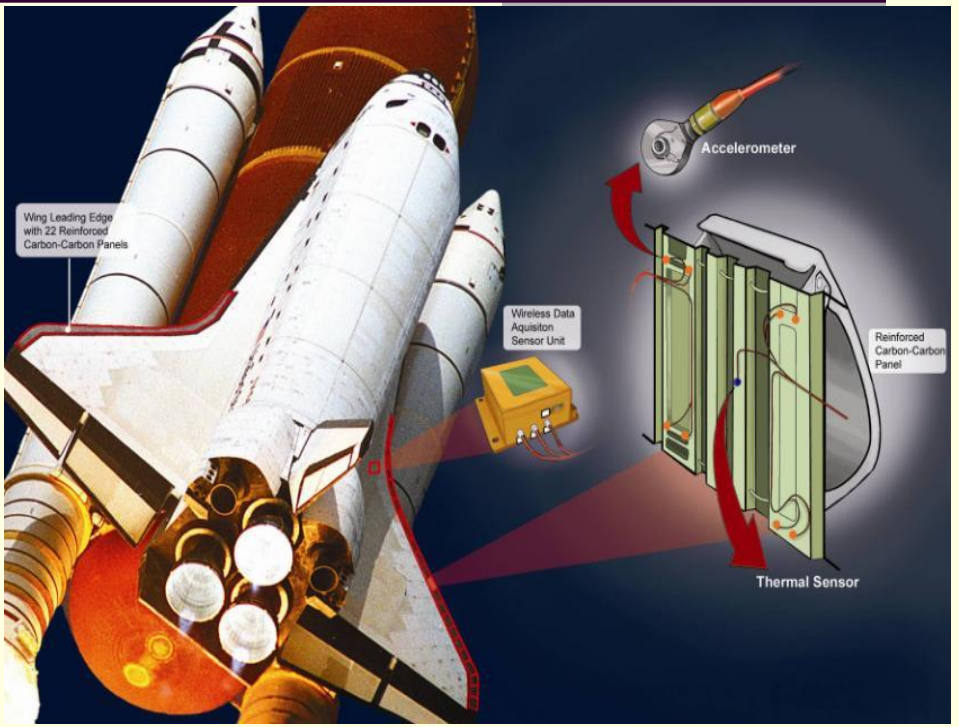
- Shuttle return to flight
- In-flight inspection
  = primary safety assurance
- Impact Detection System
  = important to identify damage
  - Notify of occurrence
  - Pinpoint location
  - Simplified inspections
- Used for
  - Launch to Orbit
  - MMOD while orbiting



Hardware:
44 sensor units , 22 per wing, mounted in 2 locations
Each unit has 3 accelerometer channels & 1 thermal sensor
132 accelerometers mounted inside wing spare panel

Wing Leading Edge Impact Detection System

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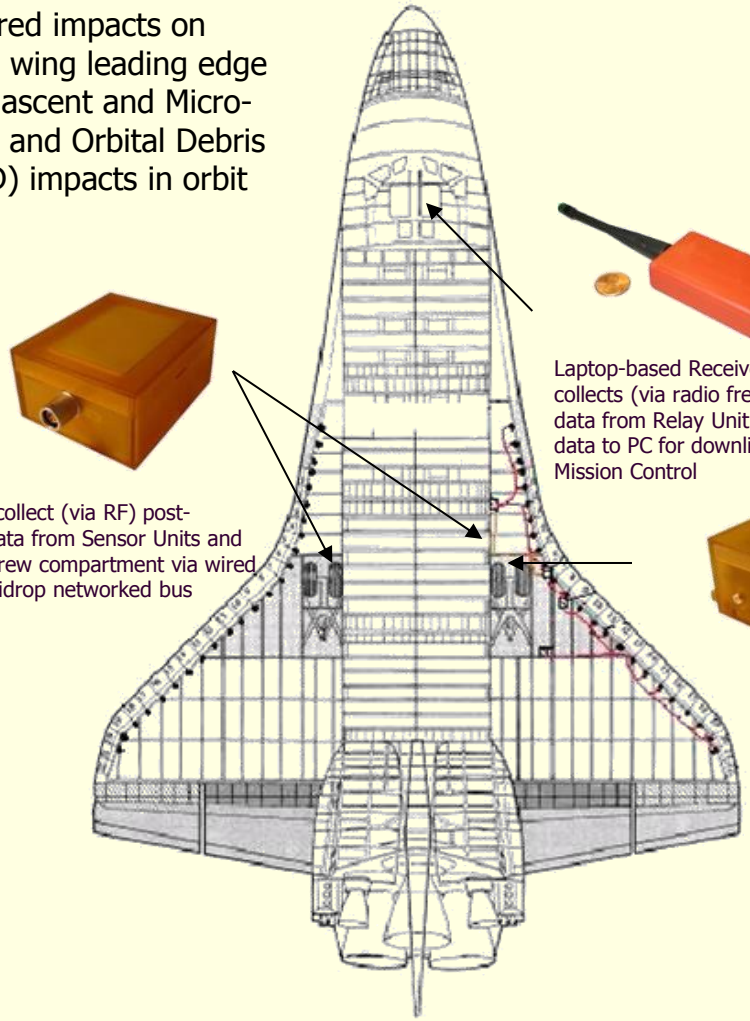
Monitored impacts on Shuttle wing leading edge during ascent and Micro-Meteor and Orbital Debris (MMOD) impacts in orbit



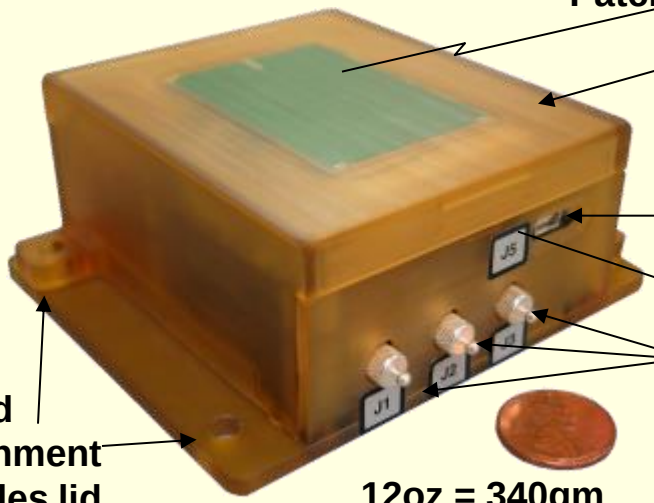
Laptop-based Receiver Assembly collects (via radio frequency) data from Relay Unit and dumps data to PC for downlink to Mission Control

Relay Units collect (via RF) post-processed data from Sensor Units and transfer to crew compartment via wired RS-485 multidrop networked bus

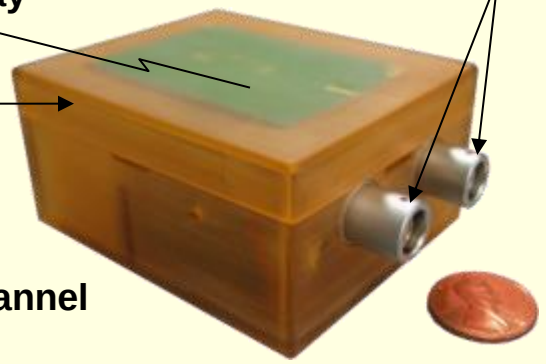
Sensor Units record and post-process accelerometer and temperature readings during ascent and while on-orbit

WLEIDS Hardware Overview

Enhanced Wide Band Micro Tri-axial Accelerometer Unit
(EWBMTAU)



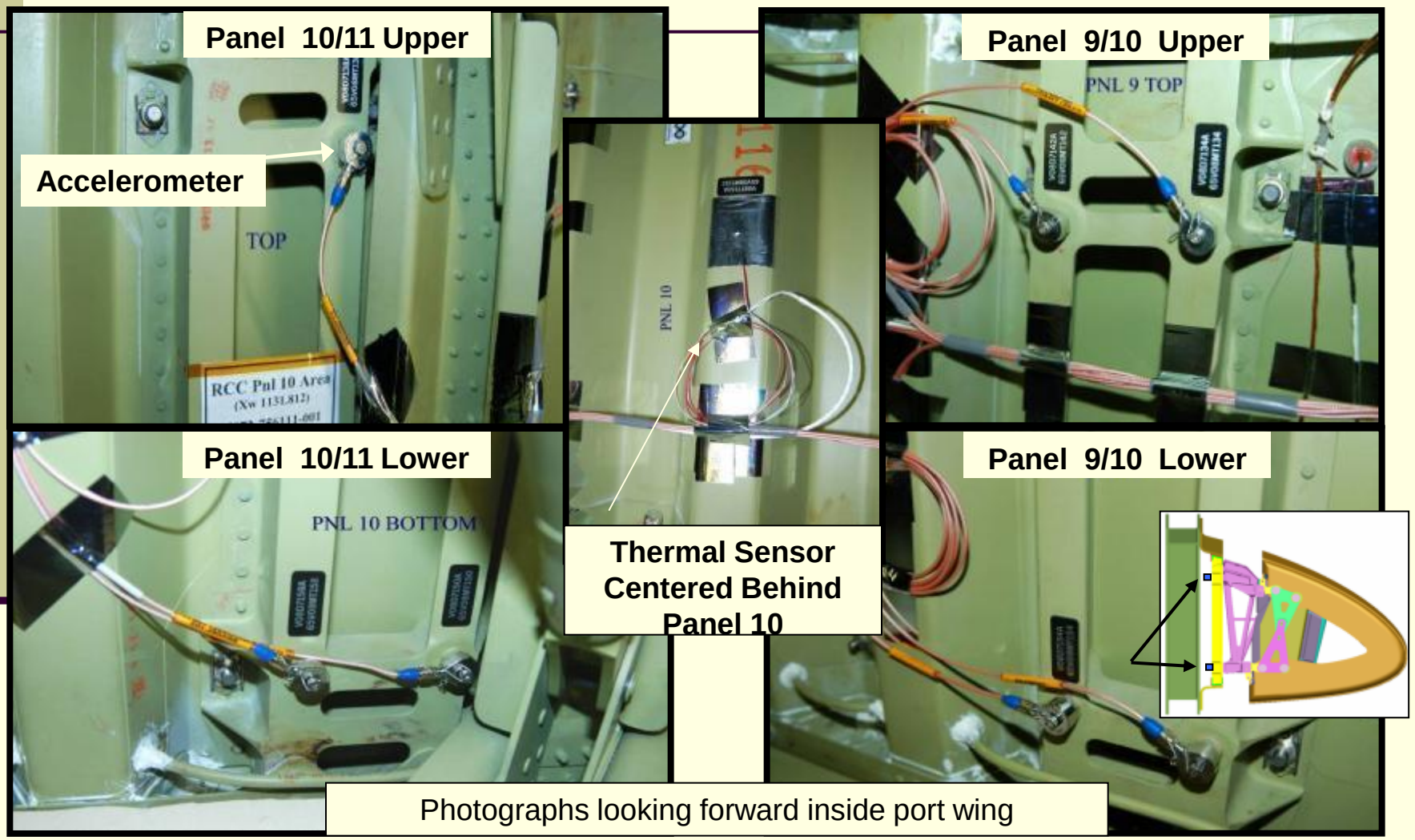
Cabin Relay Unit (CRU)



- <u>Accelerometer:</u> Piezoelectric Charge Output
  Endevco 2221F / 0.39 oz = 11 gm / .966” x .6” x .52”
- 10 pC/g sensitivity
- Bolted to a nut-plate with fastener/washer
- Sinusoidal vibration limit: 100 g pk
- Shock limit: 3000 g pk

WLEIDS Accelerometer Installation

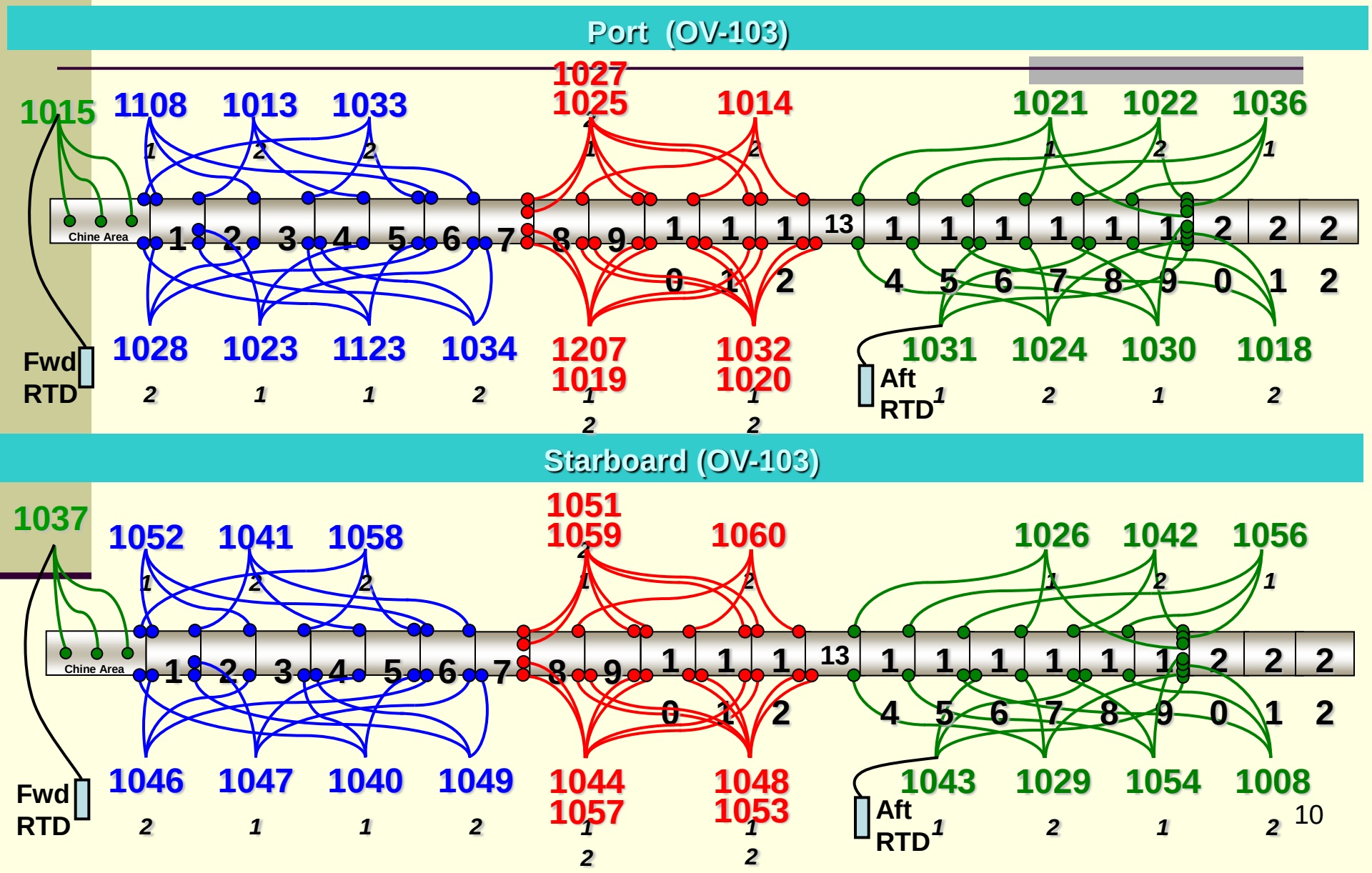
Accelerometers installed behind WLE spar near the upper/lower attach bolts for RCC Panel assemblies



Photographs looking forward inside port wing

Sensor Configuration for Ascent Monitoring

Cross-strapping for Quadruple Redundancy



Implementation Details

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- First Flight – Trigger levels
  - Optimal levels unknown
  - Set very low to insure that all meaningful events were captured
    - Flood of data – levels increased for subsequent flights
    - Compared data with in-flight and ground inspections
- Expanded operations
  - Micro-Meteroid and Orbital Debris (MMOD) Mode
    - Probability of impact with MMOD is increasing significantly
  - Used to monitor vehicle during orbit
  - Reduce Redundancy – increase time

NASA Photo

Simplify by Automated Processing

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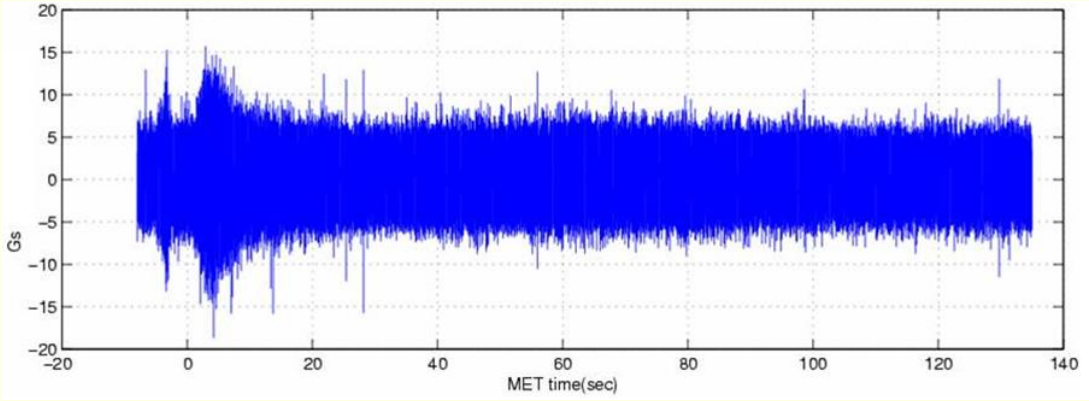
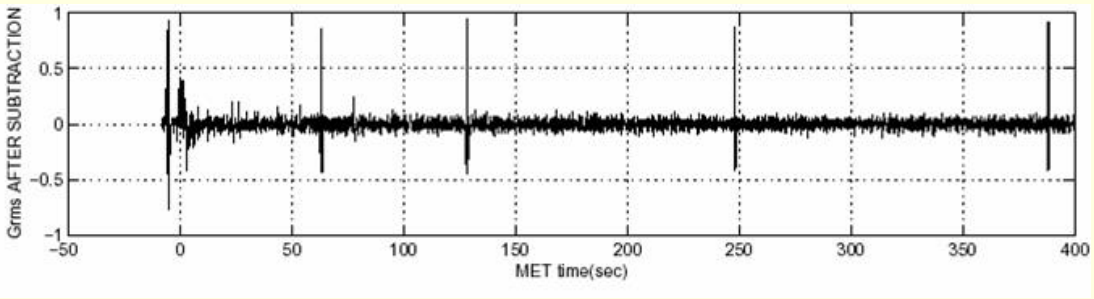
- Too much data to download in flight!
  - 256 MBytes x 44 units
  - 11 Gigabytes
- Must process data onboard each sensor unit
- What to Download?
  - List of impact events prioritized by level
  - Processed data
  - Some raw data if required
  - All data after landing



Raw Flight Data



Processed Data showing Impact Events

Distributed Impact Detection System (DIDS)

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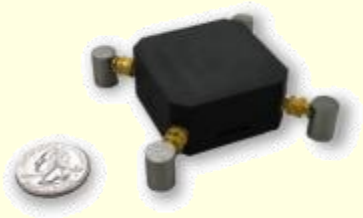
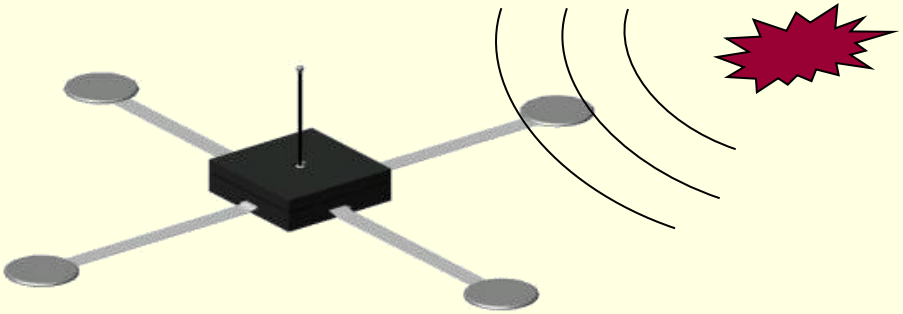
- Provides ultra low power impact detection circuitry designs for continuous monitoring of structure for accelerations or high rate strains caused by impacts throughout all mission stages
  - Sample rate: ~900 kHz
  - 4 channels / device
  - Low-power trigger modes
  - A/E, Acceleration, Ultrasonic



- Wireless communication decreases implementation cost
- Present ISS applications:
  - Leak location
  - Impact detection on BEAM



Launch Vehicle Instrumentation

- The following systems are designed to increase the capabilities of launch vehicles while decreasing cost.
- Some cost reduction is through simplified integration
- *Some* of these devices include wireless interfaces.
- *All* of these devices are designed to be used with wireless telemetry.

- These systems are examples of instrumentation for systems that **cannot be inspected** due to the nature of their missions.

Hit Detection/Location Systems

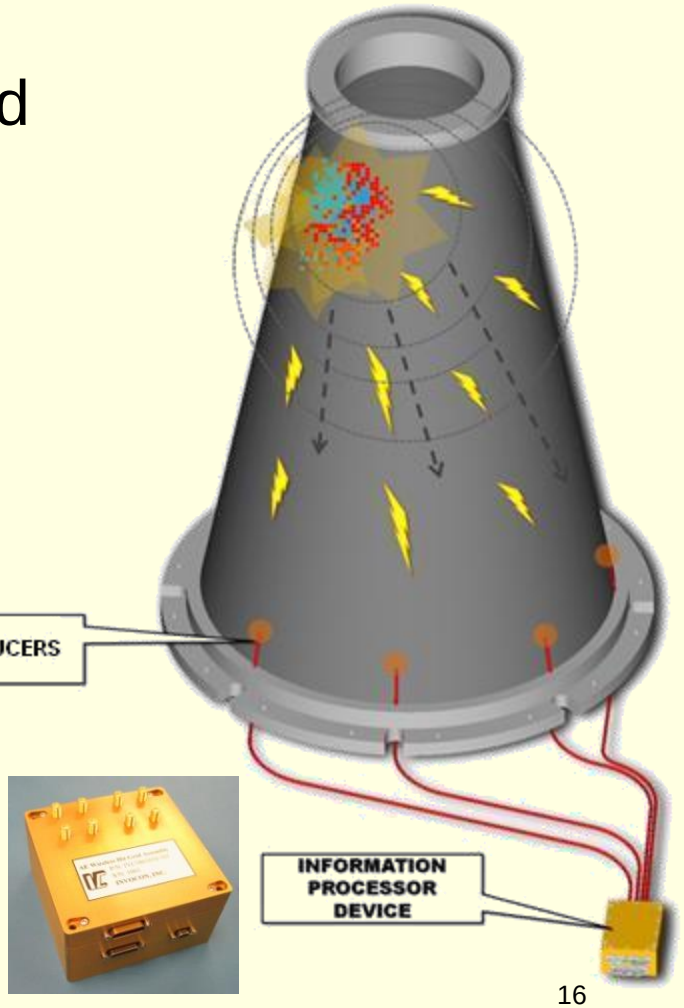
- Telemetry Data Acquisition System - TDAS
  - Measures the response of a grid of up to 256 coaxial wires – 160 ns sampling
  - Telemeters data to Ground Receiving Units (GRUs) at 10Mbps
  - Self contained (power and communication)
- Kinetic Impact Position System – KIPS
  - Low cost version of TDAS
  - Integrates with vehicle power and communication
  - 80 ns sampling
  - Intelligent com link sharing to insure all important data is transmitted
- Have provided impact location for 20+ vehicles

TDAS

KIPS

Grid-less Hit Grid (Patented)

- Grid-less transduction technology replaces or augments wired hit grid
  - Acoustic and/or RF sensing
- Simplifies integration
- Installs on vehicle skin
- Reduces weight
- Provides enhanced situational awareness
- Enables detection of multi-impact events (i.e., Shrapnel kill weapon)



Hypervelocity Impact Damage Assessment System

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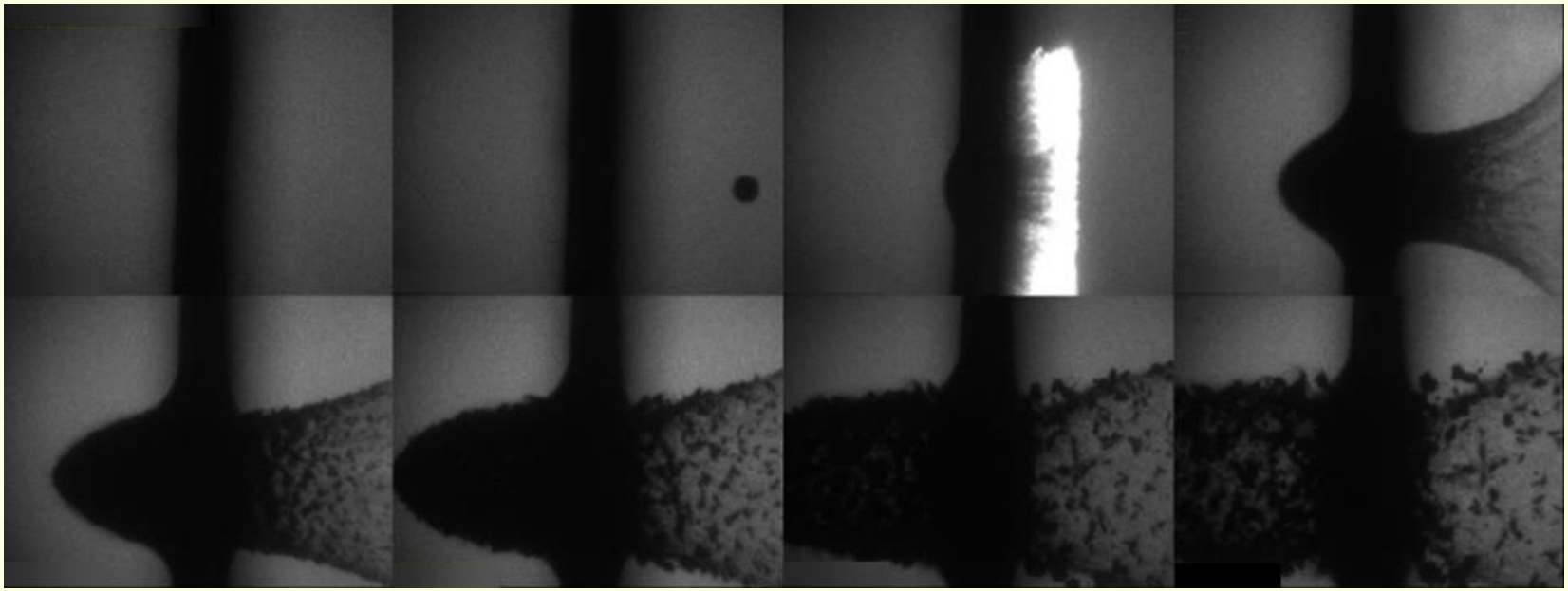
- Phase I SBIR
- Expands from *detection* and *location* to *evaluation*
- Characterize HVI signals
- May have limited time after HVI event to evaluate damage
- Much work to be done!



Surface-borne Time of Arrival Measurements (STORM) (Patent Pending)

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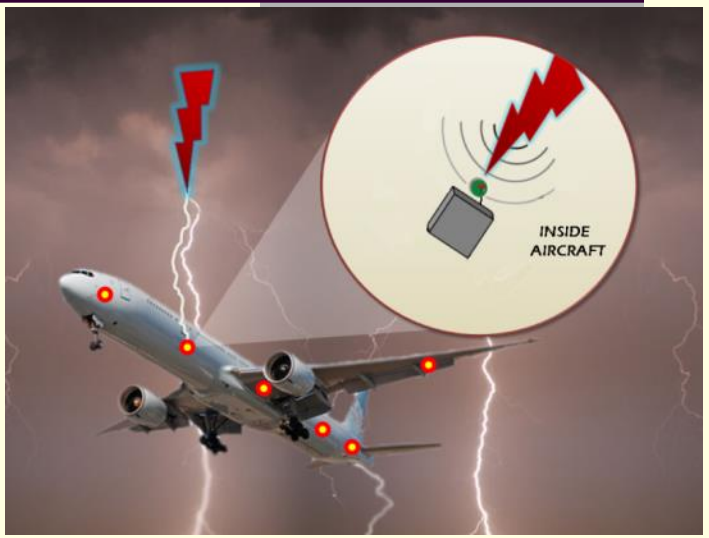
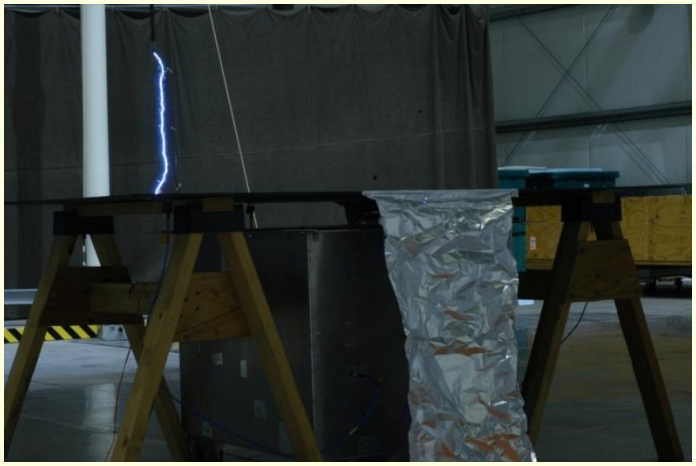
- Designed to detect, locate, and evaluate lightning strikes on aircraft
  - Immediate feedback to flight crew
  - Detailed feedback to maintenance personnel
- Sensing is similar to HVI technology
- Developed technology to simplify installation and operation
  - Key objective of recent work





New Wireless HVI Detection and Location
(Patent Pending)

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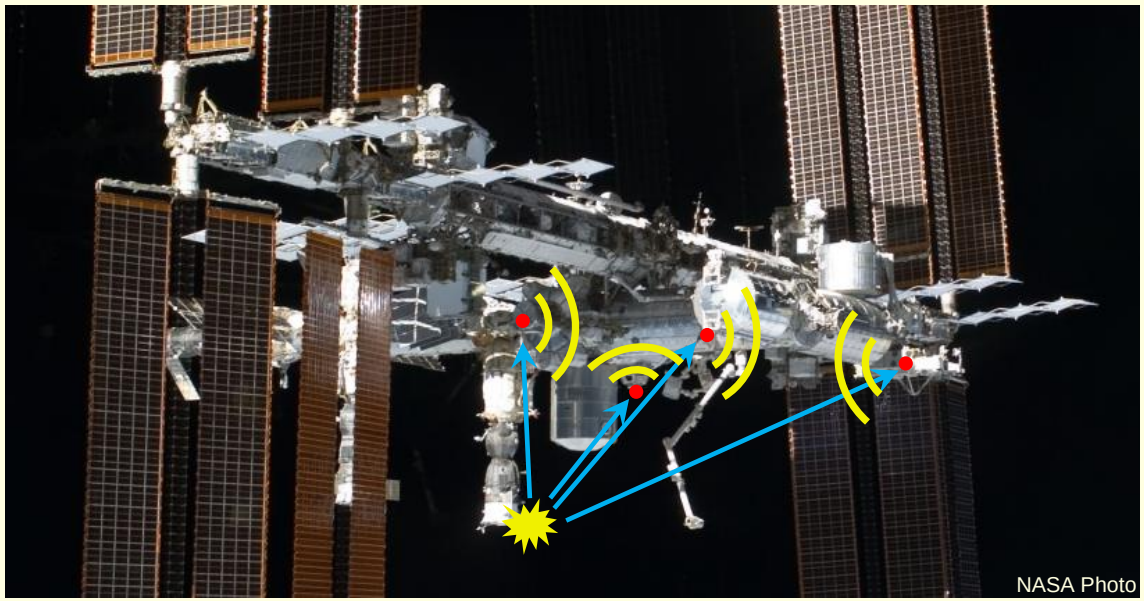
- Distributed wireless sensor network
- Based on heritage impact location and new wireless synchronization capabilities
  - Wireless distributed synchronization to better than 1 nano-second!
  - Simple hardware and low bandwidth minimizes cost. ($ and resources)
  - Simplifies installation and operation.
- Applicable to wide range of instrumentation
  - Can increase efficiency of RF Communication



Summary

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- Event-triggered inspections are used by NASA in critical applications
- Impact detection and location are particularly useful in aerospace applications where structural mass is minimized
  - Lower safety margin than other applications
  - Impacts are a real possibility
- Cost-effective (Time and $$$)
- Minimizes exposure of structure to potential for additional damage

Acknowledgments

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